Formation Evaluation in Shale Prospects Experience in Argentina Vaca Muerta Formation*

Martin Paris[1]

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[1]Geoscience Coordinator, Baker Hughes, Buenos Aires, Argentina (Martin.Paris@bakerhughes.com)

Abstract

Although the terms "formation evaluation" are equally applied to both conventional reservoirs and shale prospects, their objectives, log-based quantifiable properties, lab measurements, and processes are distinctly different. This demands a change in workflows, mindset and paradigms of the Geoscience professionals, who had to walk through the learning curve at a fast rate, with the support of experience in the U.S.A. In Argentina, with over three years of learning in the Vaca Muerta Formation, a workflow has been created to evaluate this formation. This workflow, which encompasses log analyses, lab measurements and calibrations, is presented in this paper. Relevant properties must be summarized following quantification to proceed to decision-making. This is aimed at answering some questions, such as: Which intervals should be hydraulically fractured and which intervals should not? Which is the best interval to navigate in a horizontal well? It is worth mentioning that there are many properties that could be major drivers that determine the productivity of this prospect, being added and studied

progressively and methodically as projects move forward. Therefore, formation evaluation in unconventional prospects should not be deemed as the final product of a static science, because, as any process of knowledge creation, it evolves over time.

References Cited

Paris, M., et al., 2014, Evaluacion De La Formacion Vaca Muerta En Un Pozo Exploratorio, Premisas E Incertidumbres: CONEXPLO 2014, Argentina.

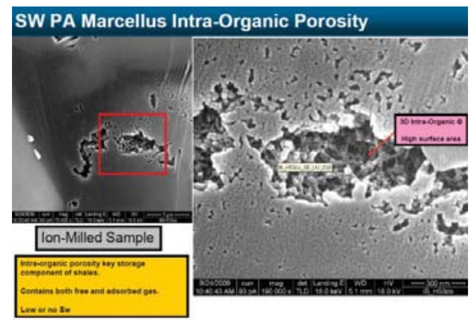
Franquet, J.A., and E.F. Rodriguez, 2012, Orthotropic Horizontal Stress Characterization From Logging And Core Derived Acoustic Anisotropies: 46th U.S. Rock Mechanics/Geomechanics Symposium, 24-27 June, Chicago, Illinois.

Franquet J., F. Méndez, M. Paris, and M. D'Onofrio, 2014, Shale Reservoir Characterization using Edge Leading Openhole Logging: CONEXPLO 2011, Argentina.

Formation Evaluation in Shale Prospects
Experience in Argentina
Vaca Muerta Formation

Martin Paris

Formation Evaluation	
Conventional Reservoirs	Shales
Total/effective porosity	TOC / %Ro / S1
Permeability	Fracturability
Sw	Brittleness
Capillary pressure	Natural fractures
…	…
Objective	
Quantify Reserves	Hydraulic Fracture Design



Overview

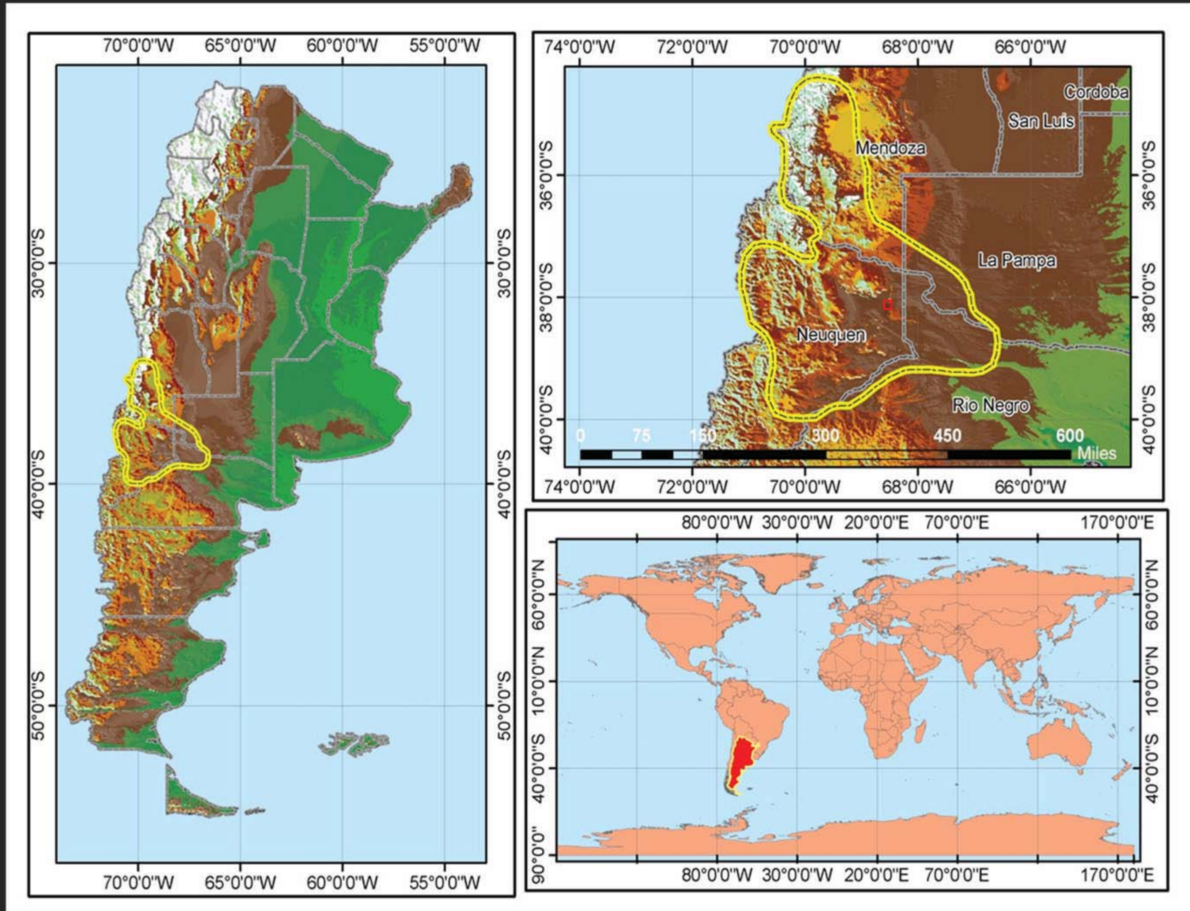
- Petrophysical Evaluation Shale Reservoir Vaca Muerta Fm. – Log suite
- Workflow
- Unconventional Sweet Spot
  - Mineralogy Log
  - Porosity
  - TOC
  - Brittleness & Mech Prop
- Why new geomechanical models?
- Traffic Lights and Validation
- Lessons Learned

Overview

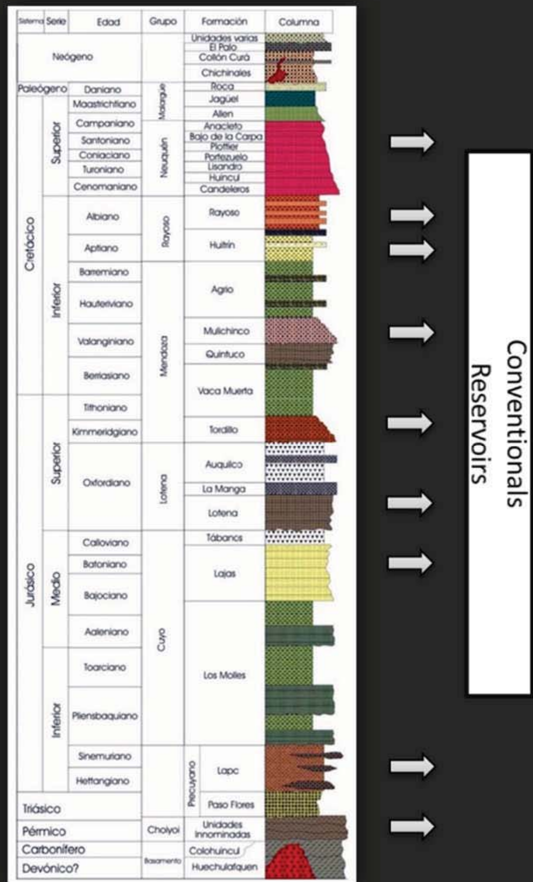
- We have learned from the Vaca Muerta Formation along three years
- What we know
- What we know we do not know

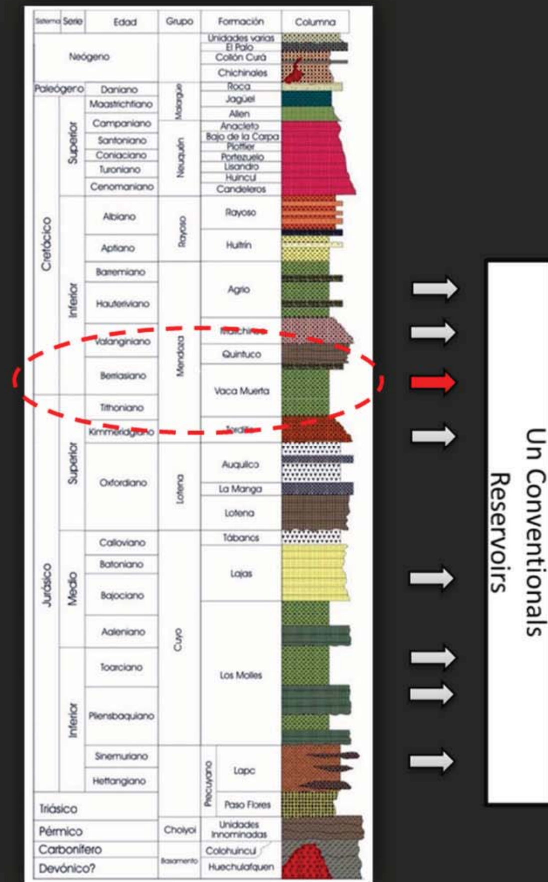
Uncertainties

Neuquén Basin Location



Reservoirs in the Neuquén Basin





Petrophysical Evaluation Shale Reservoir Vaca Muerta Fm.

Technologies Involved in Quantifying Reservoir Characteristics

Resistivity / Density / Neutron

NMR

Porosity

TOC

Fluid characterization

Mineralogy Log

Lithology

Mineralogy

TOC

Facies

Cross Dipole

Acoustic

Geomechanical properties

Image Logs

Structural and Sedimentary analysis
Stress regime determination
Fracture detection and characterization

Sidewall Core

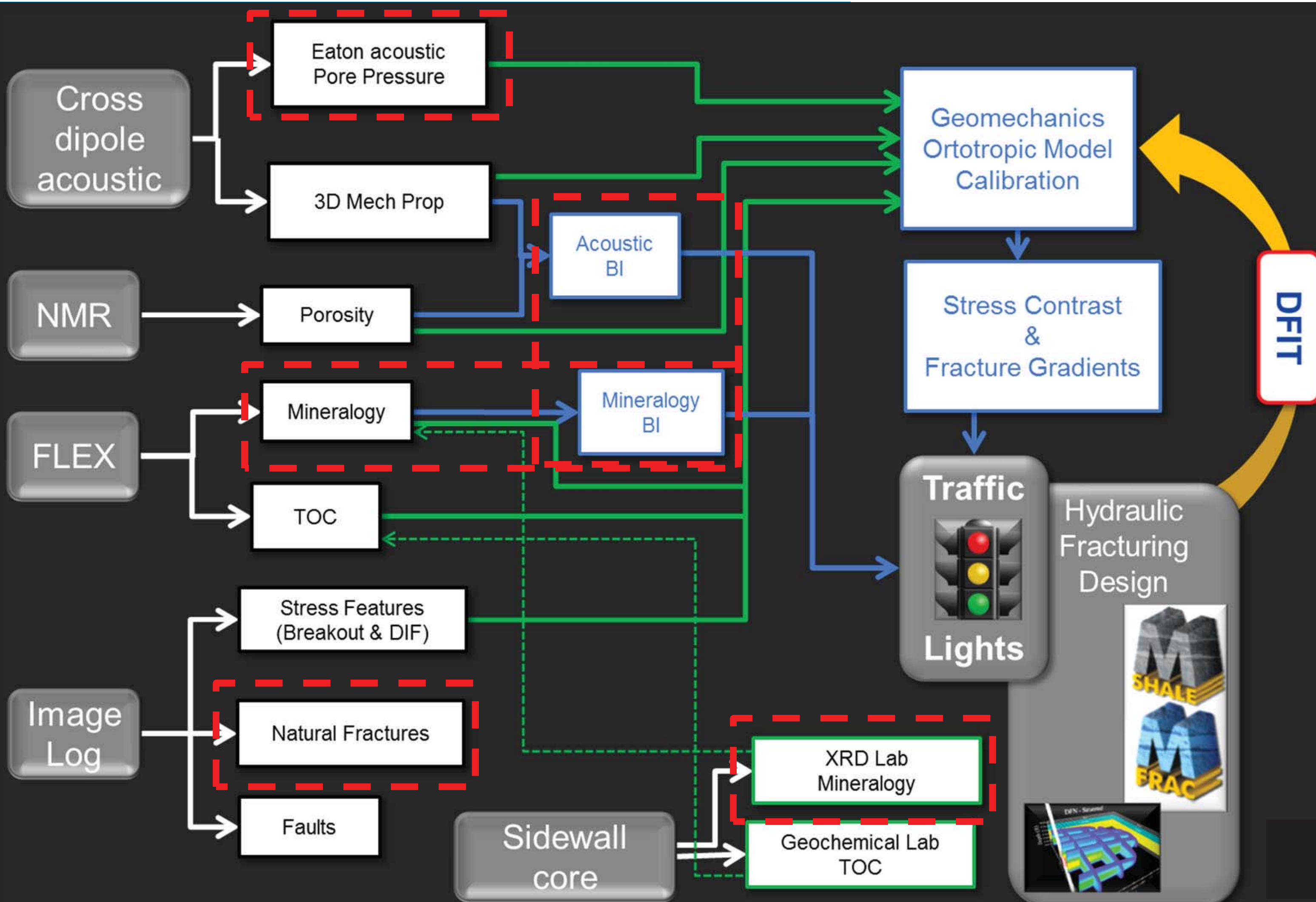
Core analysis (Phi, k, DRX, TOC,...)
Geomechanical analysis

[redacted]

Outcrops

- Lithofacies
  - Limestones
    - Planar natural fractures
    - Low embedment
  - Marls
    - Dendritic natural fractures
    - Hight embedment
  - Uncertenty Sometimes fractures on limestone are filled with calcite or gypsum. If this natural fractures are re-opened during fracking. Calcite or gypsum could seal the production (at least in one of the faces).

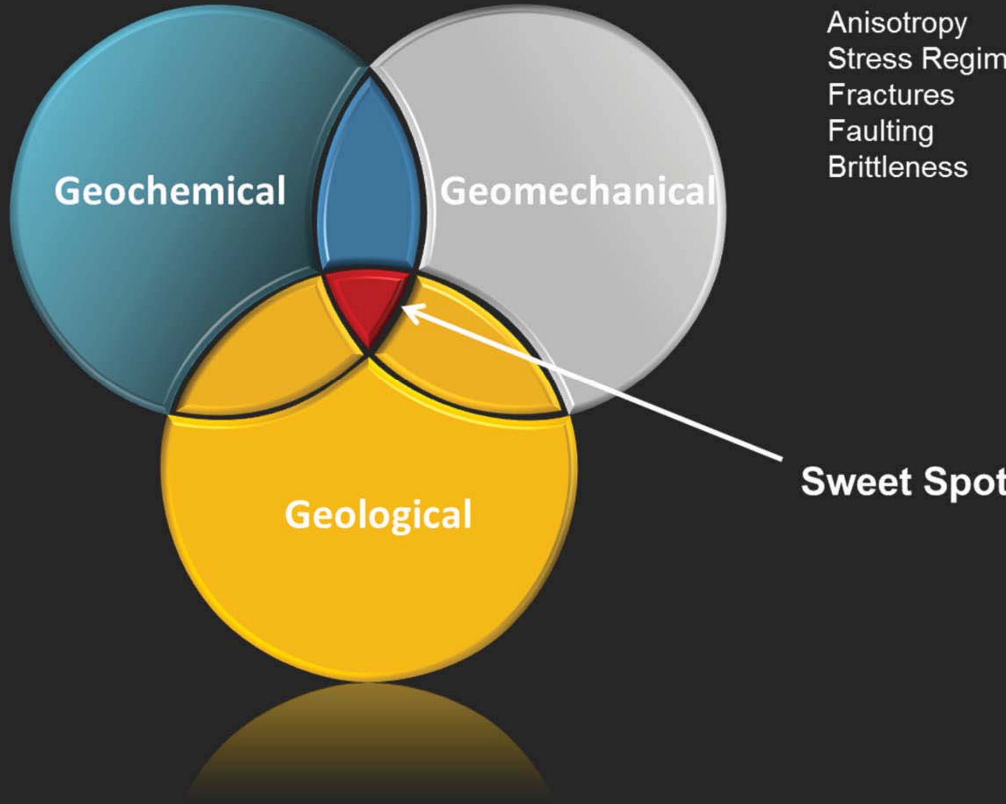
- Other features
  - Nodules
  - Beef (Thickness: 1 to 10 cm. Overpressure in source rock)
  - Ash bed (Hight Uncertenty) Thickness: 1 to 5 cm. Volcanic origin. Difficult propagation of hydraulic fracture. High embedment


Cross dipole acoustic
Eaton acoustic Pore Pressure
3D Mech Prop
NMR
Porosity
Acoustic BI
FLEX
Mineralogy
Mineralogy BI
TOC
Image Log
Stress Features (Breakout & DIF)
Natural Fractures
Faults
Sidewall core
XRD Lab Mineralogy
Geochemical Lab TOC
Geomechanics Ortotropic Model Calibration
Stress Contrast & Fracture Gradients
Traffic Lights
Hydraulic Fracturing Design
SHALE
FRAC
DFIT

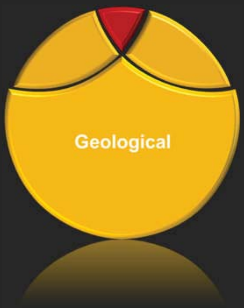
Unconventional Sweet Spot Characteristics

TOC
Kerogen Type
Fluid
Maturity
Depositional
Environment

Anisotropy
Stress Regime
Fractures
Faulting
Brittleness

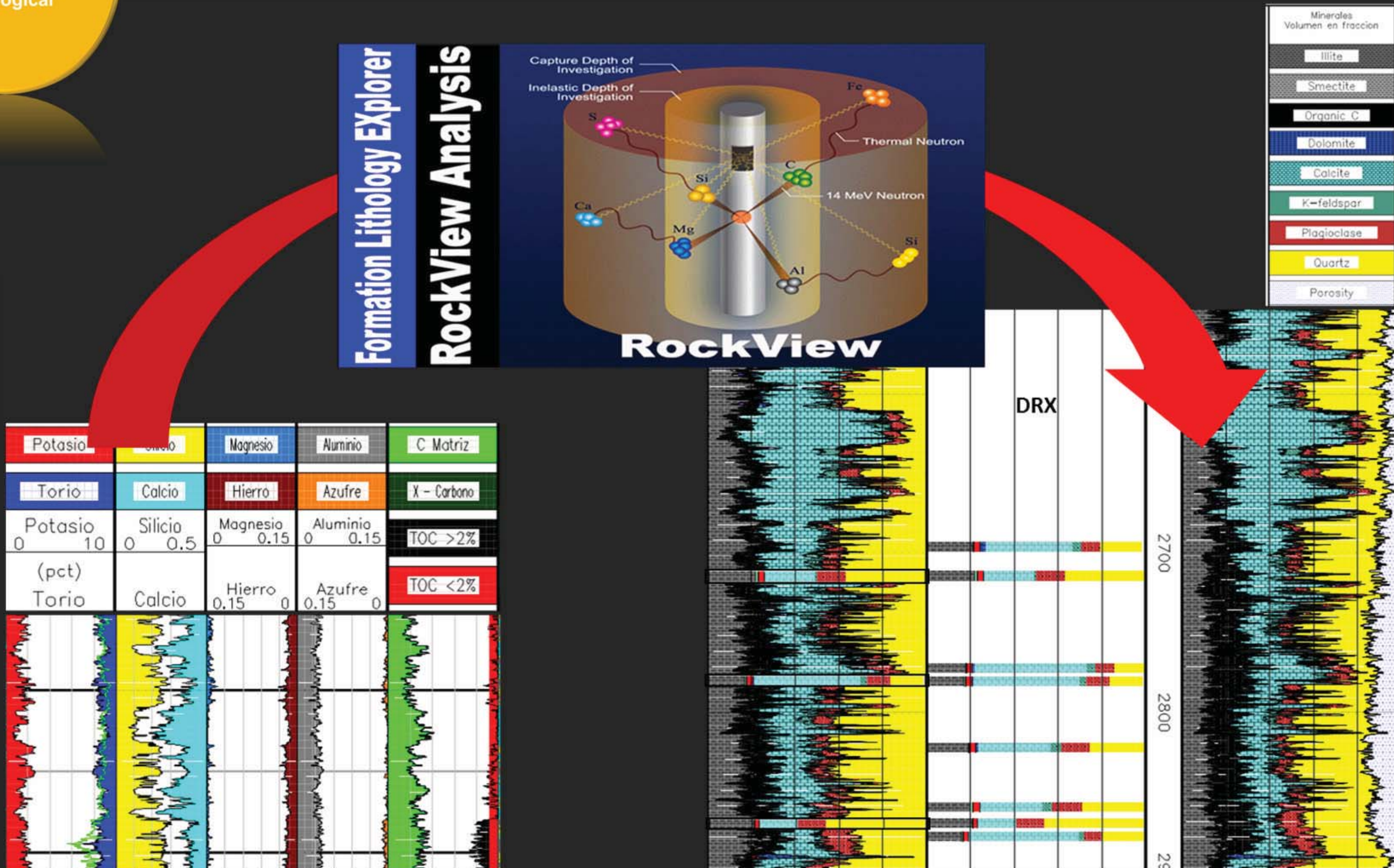


Depth
Thickness
Lithology/Mineralogy
Porosity
Pressure

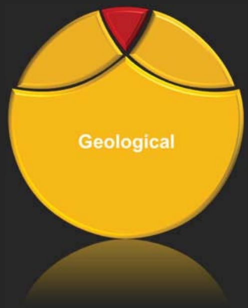


Mineralogy Log

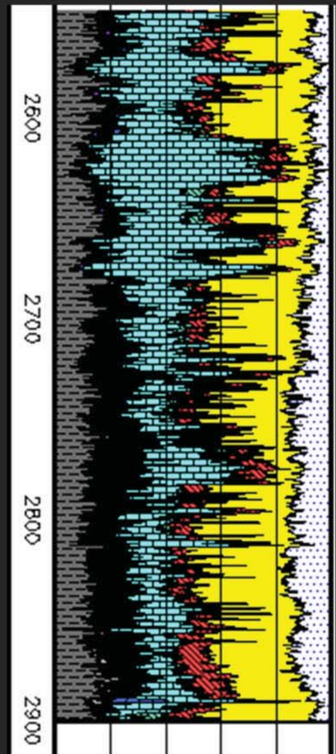
- INPUT – PROCESS - OUTPUT

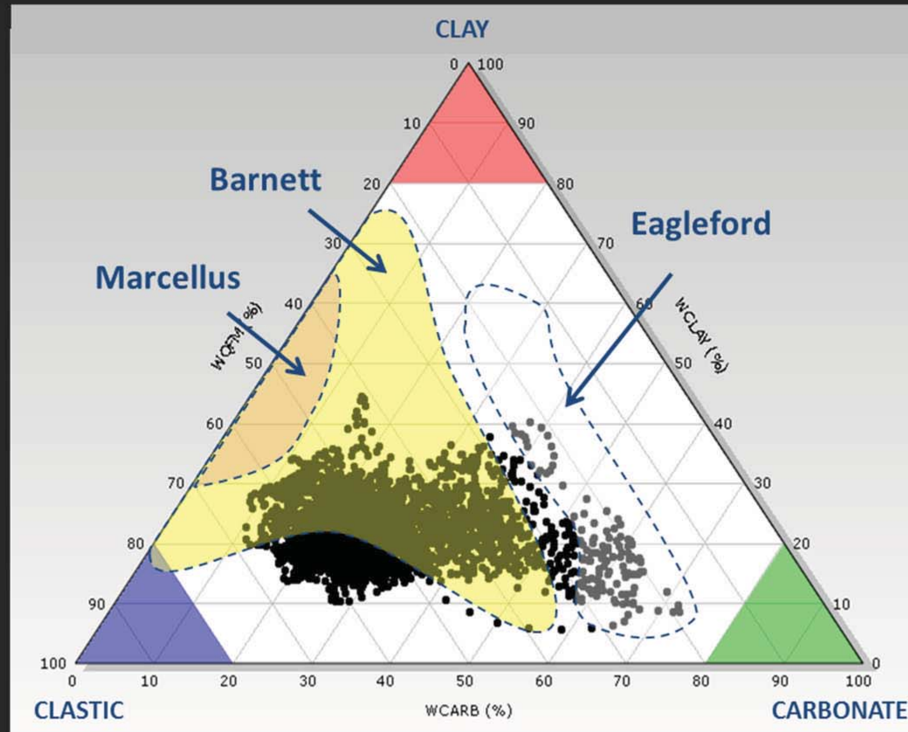


Mineralogy from FLEX

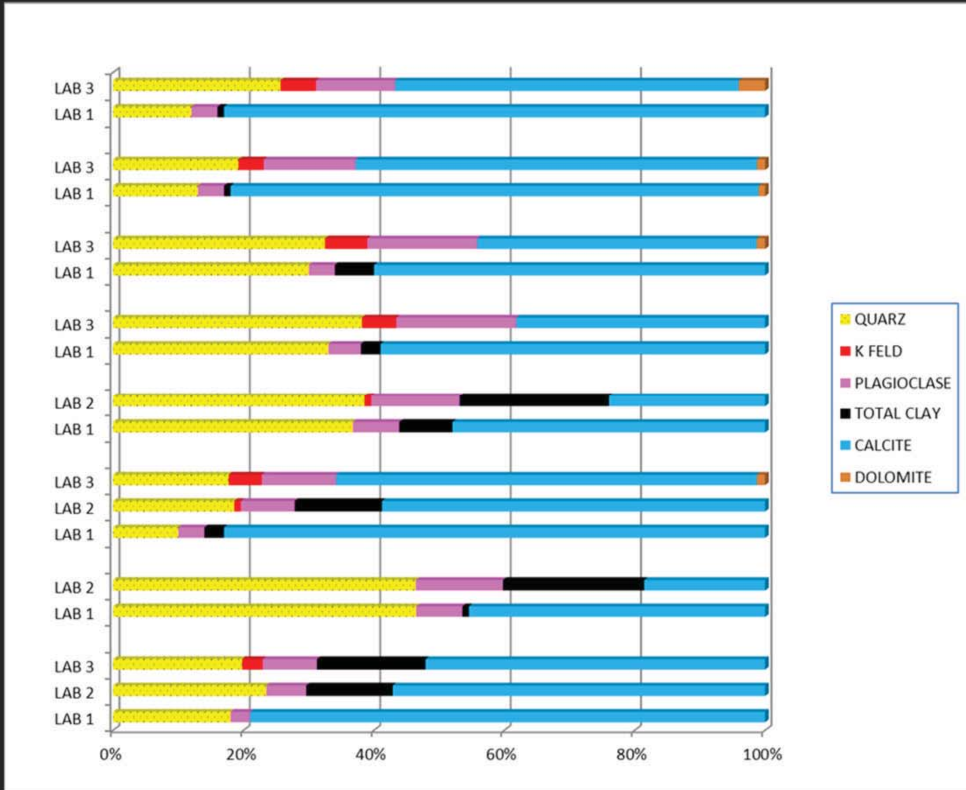


Minerales Volumen en fraccion
Illite
Smectite
Organic C
Dolomite
Calcite
K-feldspar
Plagioclase
Quartz
Porosity





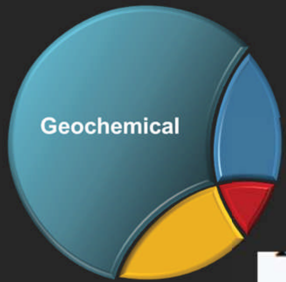
To bear in mind



DRX LAB´s Comparison

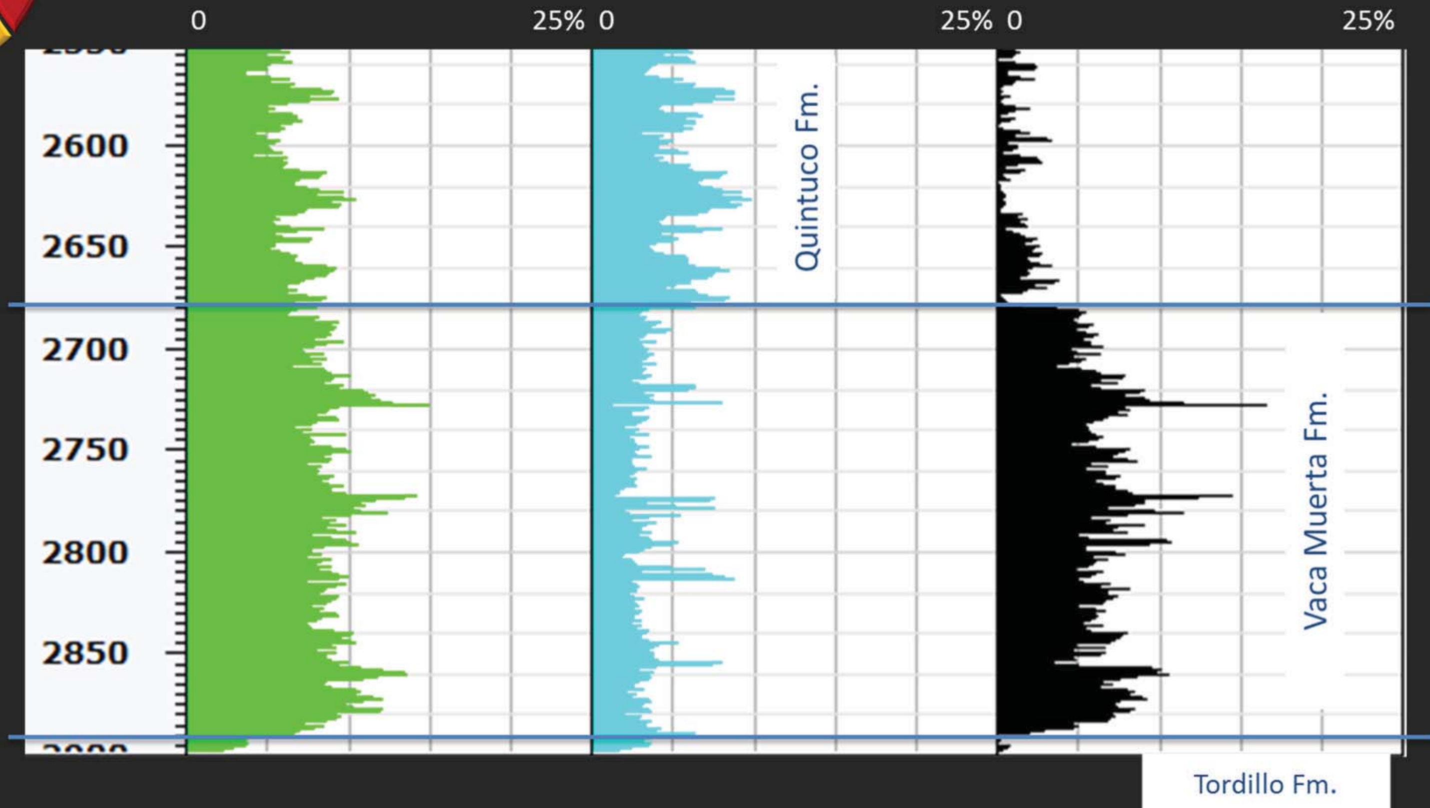
- ✓ Minor uncertainty in Quartz.
- ✓ Greater uncertainty in Total Clay.

Taken from
Paris M., et al (2014) "EVALUACION DE LA FORMACION VACA MUERTA EN UN POZO EXPLORATORIO. PREMISAS E INCERTIDUMBRES." CONEXPLO 2014, Argentina

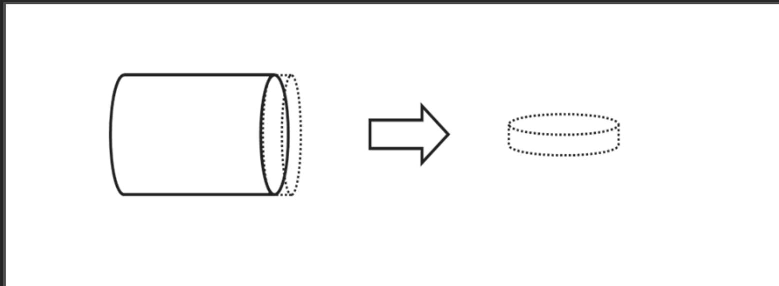


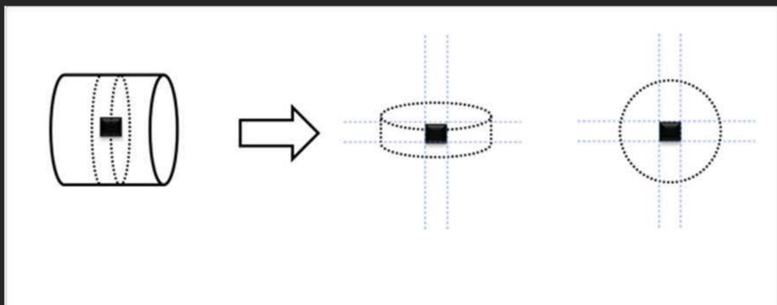
TOC

TOTAL CARBON = INORGANIC CARBON + ORGANIC CARBON



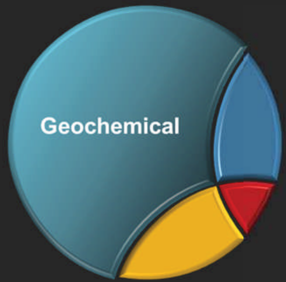
TOC



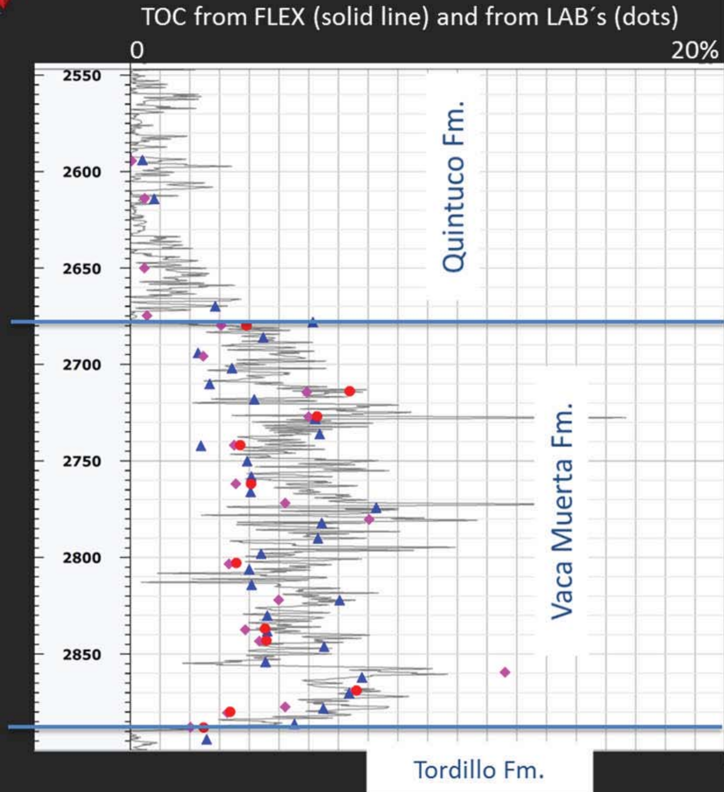


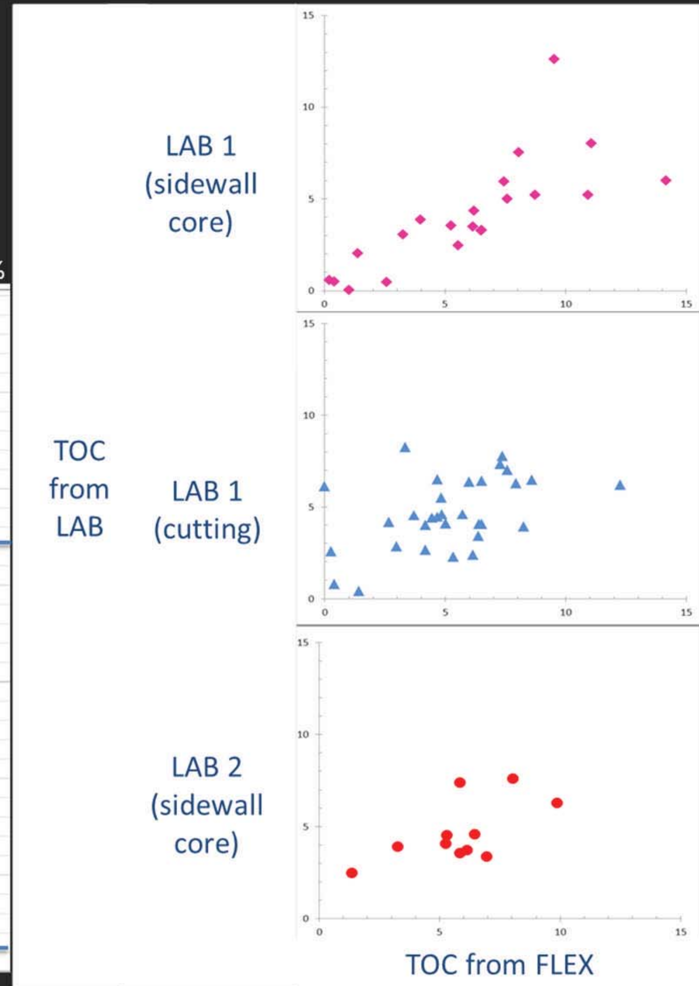
Best Practices

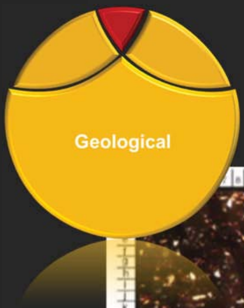
Samples are taken from the center of the rotary sidewall cores, assuming that OBM failed to reach the center of the core, as this is a low permeability formation. Here, the TOC values obtained are more consistent with the regional knowledge of the formation.


Geochemical

TOC

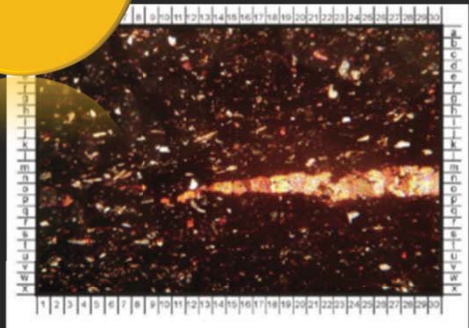

TOC from FLEX (solid line) and from LAB´s (dots)
0
20%
2550
2600
2650
2700
2750
2800
2850
Quintuco Fm.
Vaca Muerta Fm.
Tordillo Fm.

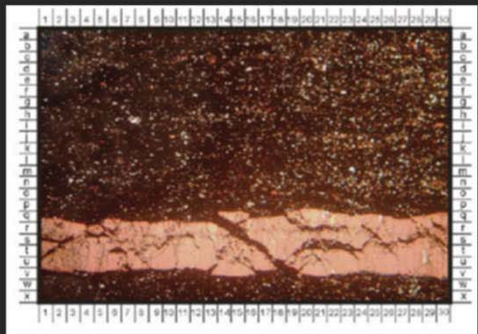

TOC from LAB
LAB 1 (sidewall core)
LAB 1 (cutting)
LAB 2 (sidewall core)
TOC from FLEX
0
5
10
15

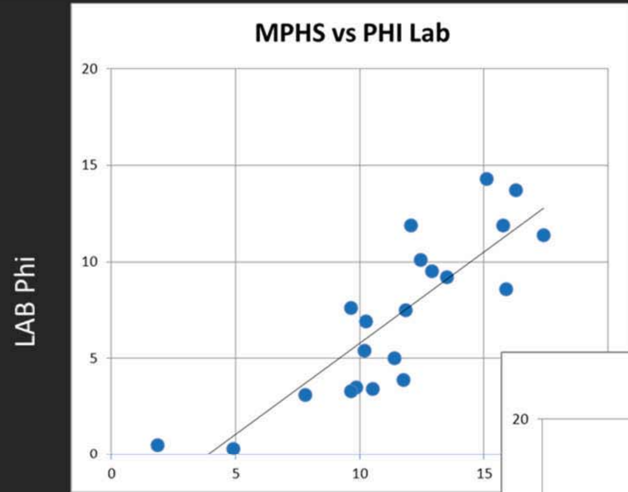


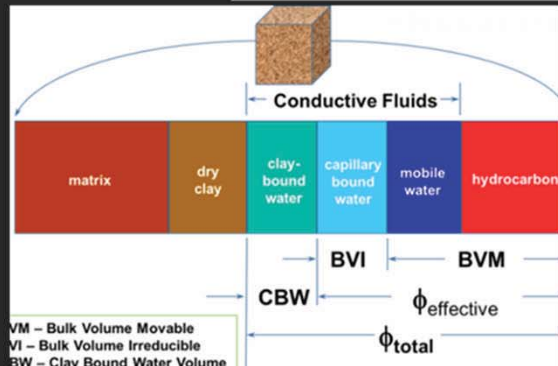
Porosity

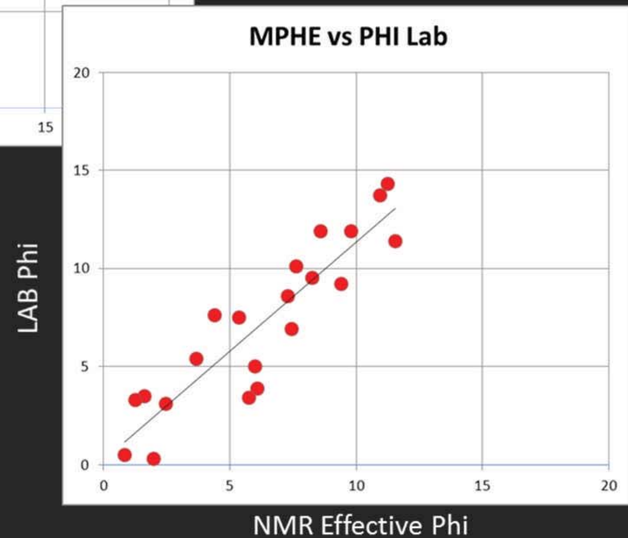
NMR vs. LAB



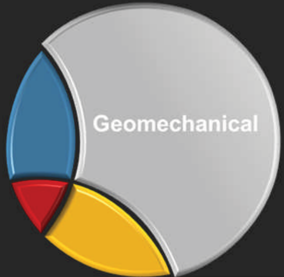




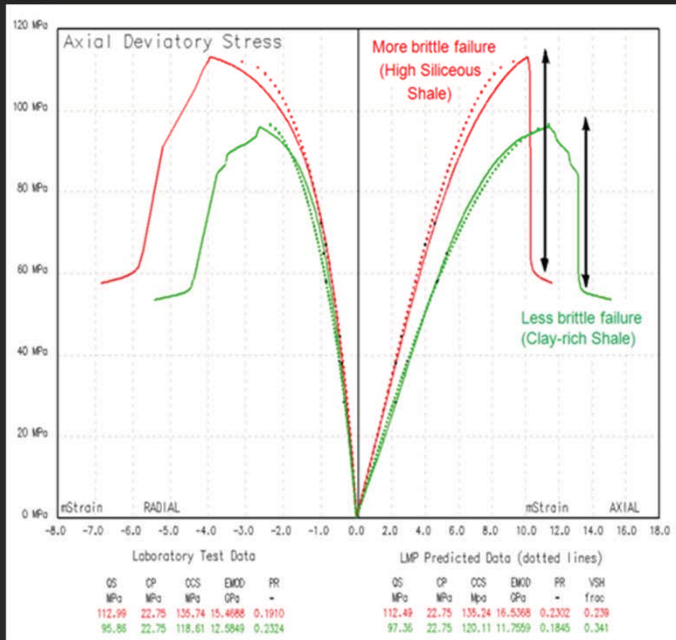




- ✓ **LAB porosity shows a perfect fit with NMR effective porosity.**
- ✓ **Total porosity is used in geomechanics and petrophysics calculations.**



Brittleness



Taken from
Franquet J., et al (2014) "Shale Reservoir Characterization using Edge Leading Openhole Logging" CONEXPLO 2011, Argentina

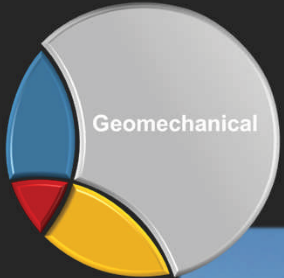
- **Brittleness Indicators computed from:**
  - **Mineralogy:** Mineralogy Brittleness Index
    - Studies in several shale plays suggest that as the amounts of of silica and carbonate present in the rock increases the rock's brittleness increases.
  - **BIM** $= \dfrac{\%\text{ wt. fraction QFM + CARB}}{\%\text{ wt. fraction QFM + CARB + CLY + TOC}}$
    - Generally, the higher the BIM the more brittle the interval.

Geomechanical brittleness and hardness

- **Brittleness Index:** Derived from Young's Modulus and Poisson's Ratio.
  - A high Young's Modulus (E) and/or a low Poisson's Ratio (ν) indicate brittle rock behavior

$$Brittleness = \frac{E_{index} + \nu_{index}}{2}$$

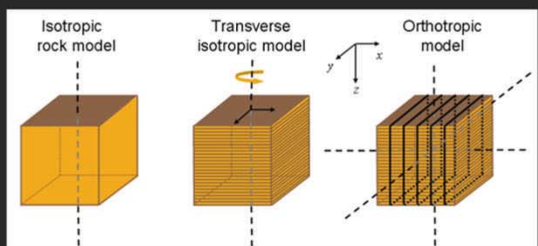
$$\nu_{index} = \frac{\nu_{max} - \nu}{\nu_{max} - \nu_{min}} \qquad E_{index} = \frac{E - E_{min}}{E_{max} - E_{min}}$$



Why new geomechanical models?

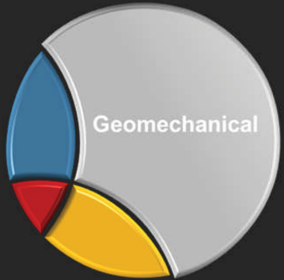
Orthotropic Model

Transverse Isotropic Model (VTI)

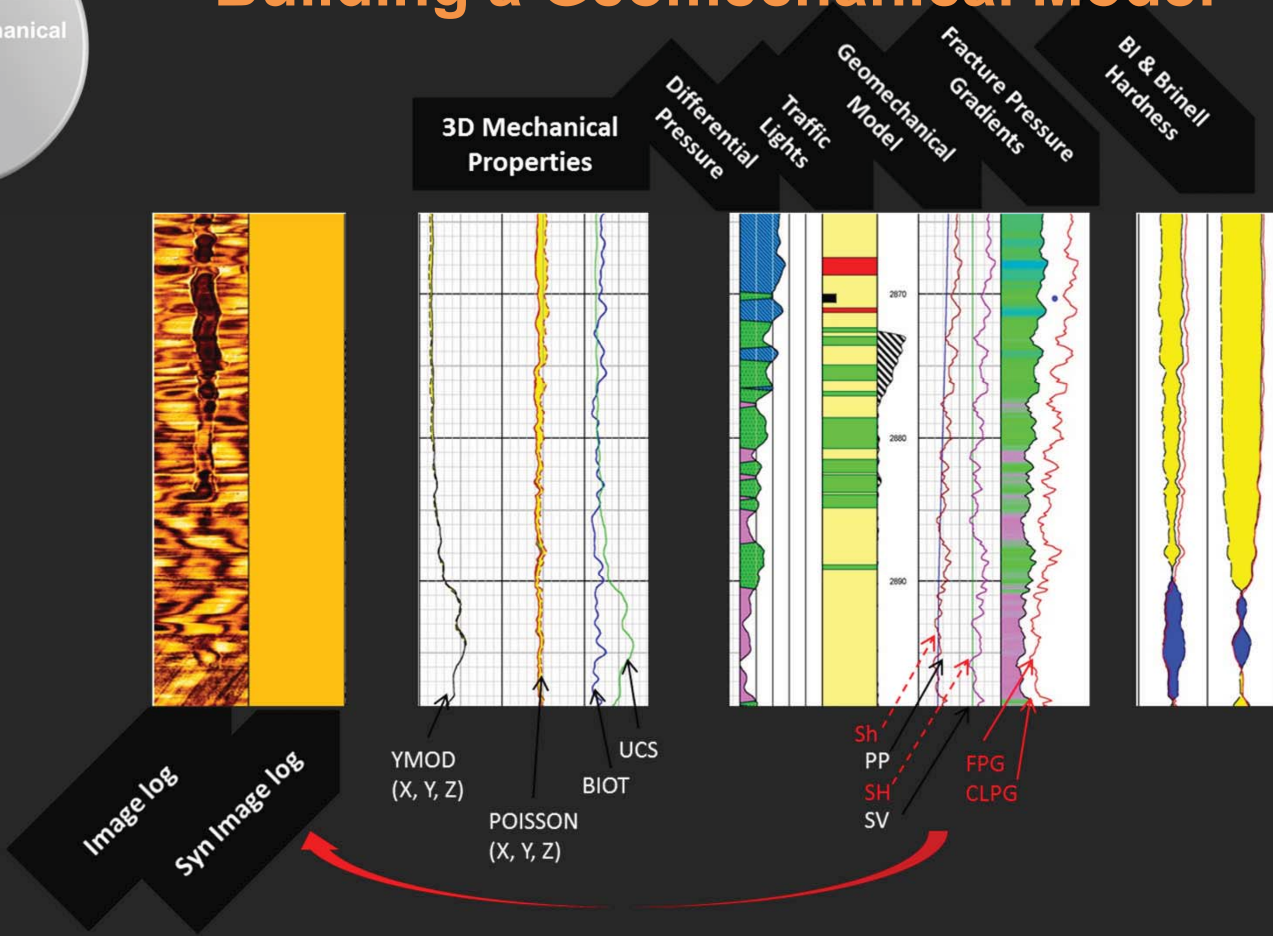


ARMA 12-644

Orthotropic Horizontal Stress Characterization from Logging and Core- Derived Acoustic Anisotropies
Franquet, J.A. and Rodriguez, E.F.
Baker Hughes, Houston, TX, USA



Building a Geomechanical Model



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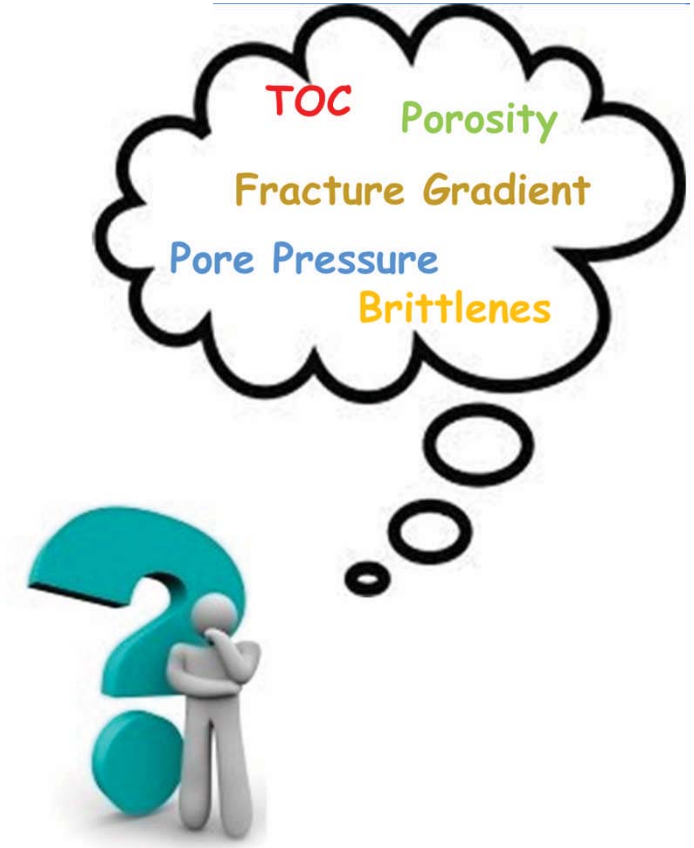
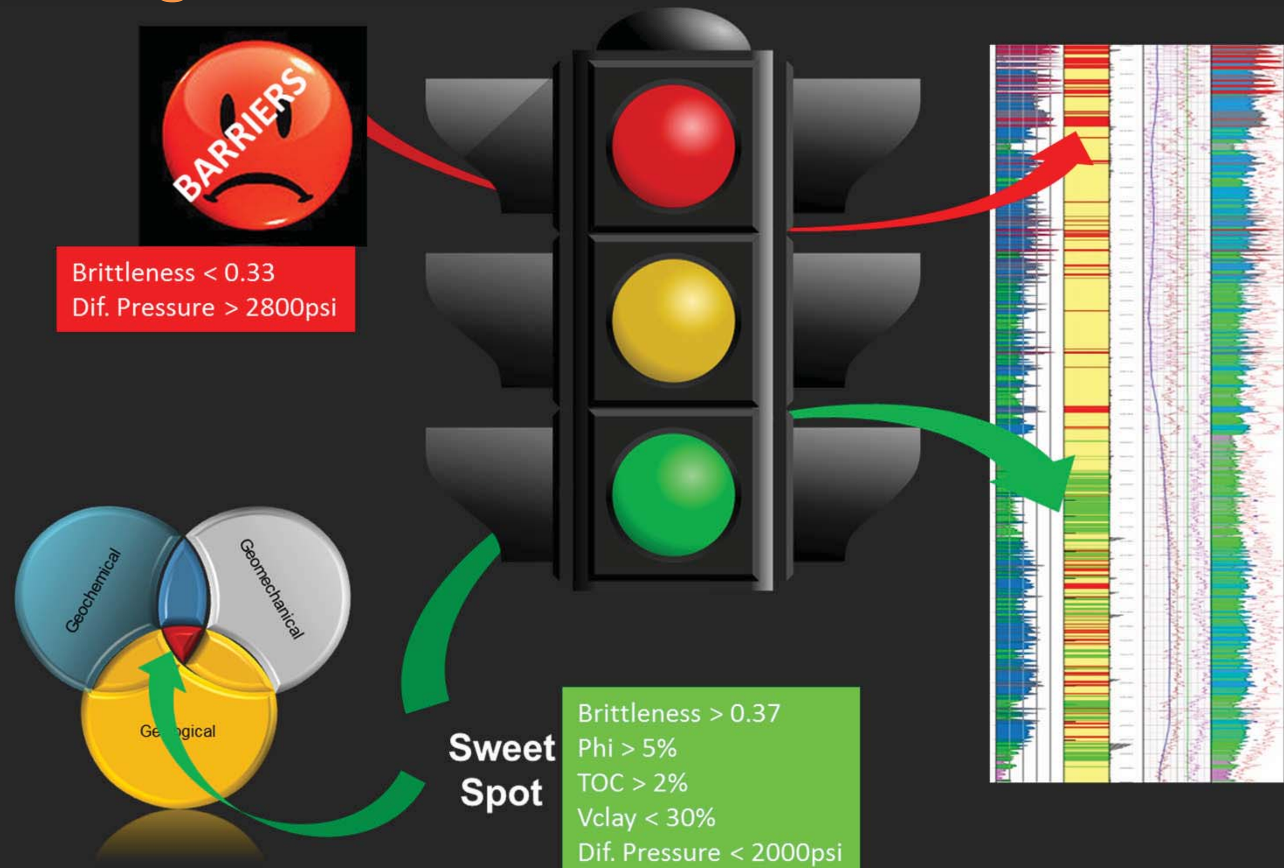
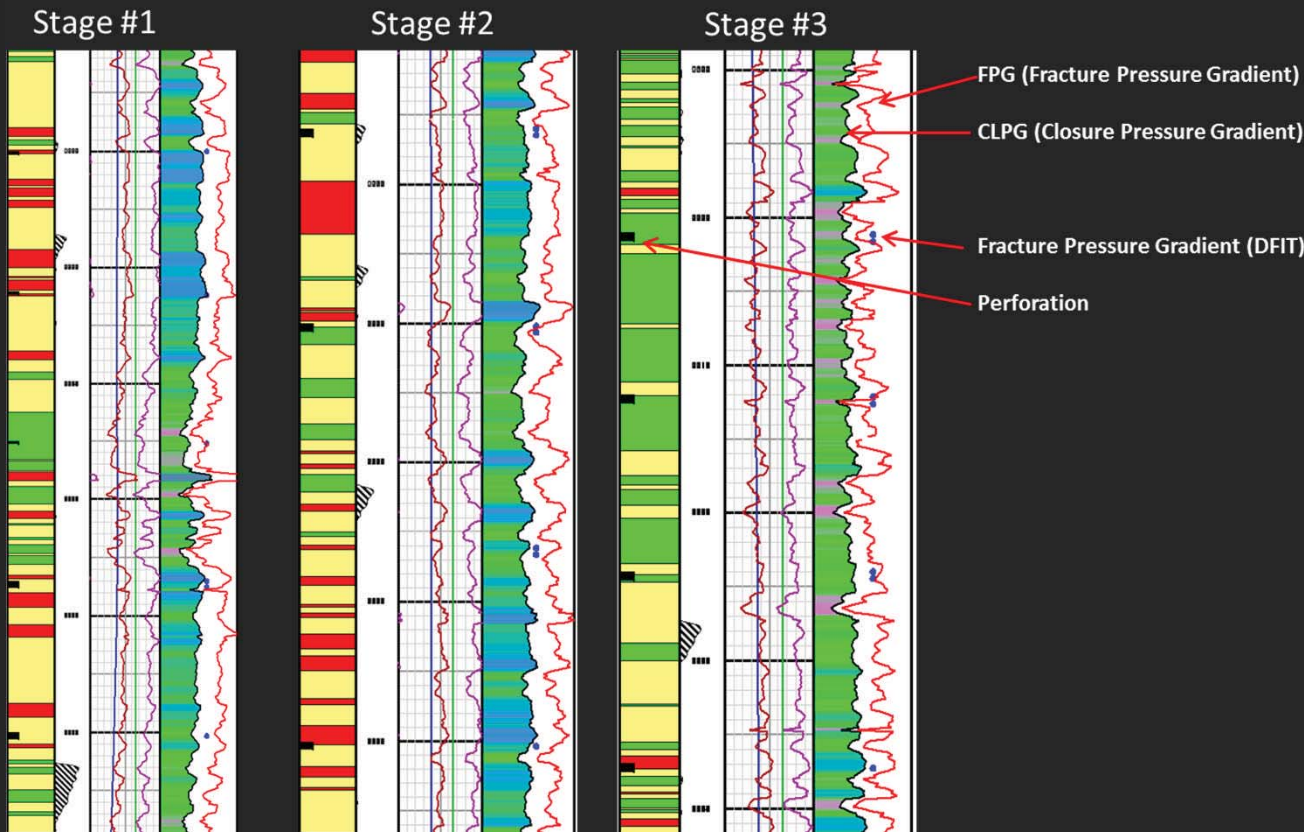

TOC
Porosity
Fracture Gradient
Pore Pressure
Brittlenes

Traffic Lights



Fracture Stages
GeoMechanical Model Validation



Lessons Learned

- A workflow is developed for the Vaca Muerta Formation
- During the exploration phase of the evaluation of a shale prospect
  - Logs with laboratory data calibration is necessary (DRX, TOC, petrophyisics).
  - However there is great uncertainty in determining the mineralogy
  - LAB porosity shows a perfect fit with NMR effective porosity.
  - TOC can be calculated from Logs with great certainty.
- Always bear in mind the uncertainties
  - Ash beds
  - Natural fractures (open, healed)
  - Pore Pressure Mineralogy
  - Brittleness
  - ...

THANK YOU